Single and multi-photon events with missing energy in e^+e^- collisions at $\sqrt{s} = 189$ GeV with the L3 detector at LEP

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Single and Multi-Photon Events with Missing Energy in e^+e^- Collisions at $\sqrt{s} = 189$ GeV with the L3 detector at LEP *

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Abstract

Single and multi-photon events with missing energy are studied in a data sample of 176 pb^{-1} integrated luminosity at a center-of-mass energy of 189 GeV with the L3 detector. Good agreement with the Standard Model is observed for the single photon channel whereas a 3σ deficit of data is seen for the 2 acoplanar photons events. These results are used to derive limits on new physics processes. Several interpretations in SUSY models providing new excluded sets of supersymmetric particle masses are presented.

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1 Introduction

Supersymmetry [1] is one of the most appealing theories which extend the Standard Model. This theory can solve the hierarchy problem of the Standard Model. It also facilitates the unification of the three gauge couplings at high energy. Finally, assuming that R-parity is conserved, the Lightest Supersymmetric Particle (LSP) is stable. This latter is very often a weakly interacting particle and thus provides a candidate for the dark matter of the universe.

In this framework, photon(s)+ missing energy signal appears when searching for two super-particles : a neutral particle A and the LSP B with A decaying in $B + \gamma$. This situation leads to single photon events via the production

$$e^+e^- \rightarrow AB \text{ followed by } A \rightarrow B\gamma$$

It also leads to events with 2 acoplanar photons and missing energy via the pair production of particles A :

$$e^+e^- \rightarrow AA \rightarrow B\gamma B\gamma$$

The missing energy is carried out by the two LSP B which escape detection. In this paper, the two following cases will be considered :

- A is $\tilde{\chi}^0_2$ and LSP is $\tilde{\chi}^0_1$
- A is $\tilde{\chi}^0_1$ and LSP is $\tilde{G}$

These kind of processes could be used to explain the CDF events [2] $p\bar{p} \rightarrow e^+e^-\gamma\gamma \not{E}_T$ X.

This search concerns the data collected at 189 GeV in 1998 with the L3 detector [3]. They correspond to an integrated luminosity of 176 pb^{-1} . All results are preliminary.

2 Event Selection

For the single photon, we select events with only one significant energy deposit in the whole L3 detector. Moreover, the shape of this energy deposit should be compatible with a photon. There is also kinematical limitations which are related to the angular acceptance of the detector and to the trigger efficiency. These limitations are translated into the following cuts :

- The photon transverse momentum should be greater than 5 GeV
- The photon should lie either in the endcaps ($14° < \theta < 36°$ and $144° < \theta < 166°$) or in the barrel ($43° < \theta < 137°$). The z-axis is the beam axis.

The 2 photons selection is rather similar to the single photon one except that here, 2 significant energy deposits compatible with photons are required. The angular acceptance for the two photons is the same than for single photon events. The energy thresholds are 5 GeV for the most energetic photon and 1 GeV for the second one. In order to reject both radiative bhabha events and events with 2 photons and no missing energy ($e^+e^- \rightarrow \gamma\gamma(\gamma)$), we add the following cuts :
if the energy of the second photon ($E_{\gamma2}$) is less than 5 GeV then :

- The total transverse momentum of the 2 photons system ($P_{t\gamma\gamma}$) should be greater than 5 GeV.

- The opening angle between the 2 photons should be smaller than 177.6°, both in three dimensions and in the plane transverse to the beam axis.

if $E_{\gamma 2}$ is greater than 5 GeV then :

- $P_{t\gamma\gamma}$ should be greater than 3 GeV.
- The 2 photons acoplanarity should be greater than 5.2°.
- Their acollinearity should be greater than 8.1°.
- The recoil mass of the 2 photons system should be greater than 20 GeV/c^2.
- The missing momentum of the 2 photons system should point at least 12° away from the beam pipe.

3 Distributions for data and expected Standard Model background

The energy distribution of the most energetic photon for both single and 2 photon selections is shown in figure 1. We see a good agreement between data and monte-carlo prediction for the total number of events (565 for 581.4 expected) and also for the shape of the distribution. The main part of the background is due to $\nu\bar{\nu}\gamma(\gamma)$ events.

Those $\nu\bar{\nu}\gamma(\gamma)$ events have been simulated with a full detector response [4] using the KORALZ [5] generator. Other backgrounds were fully simulated with GGG [6] for $e^+e^- \rightarrow \gamma\gamma(\gamma)$, BHWIDE [7] for large scattering angles bhabhas, TEEG [8] for small scattering angles bhabhas, DIAG36 [9] for $e^+e^- \rightarrow e^+e^-e^+e^-$ events and EXCALIBUR [10] for $e^+e^- \rightarrow e^+e^-\nu\bar{\nu}$ events. For each of the two processes $e^+e^- \rightarrow \nu\bar{\nu}\gamma(\gamma)$ and $e^+e^- \rightarrow \gamma\gamma(\gamma)$, the ratio between the number of simulated events and the number of expected ones is nearly 60 whereas it is nearly 4 for the other backgrounds.

Figure 2 shows the recoil mass distribution for the 2 acoplanar photons selection. Here also the main part of the background is $\nu\bar{\nu}\gamma(\gamma)$ events but a 3σ deficit of data compared to Monte carlo was observed (20 events collected for 38.3 expected).

Many checks have been done to understand this deficit. The performance of the electromagnetic calorimeter (BGO) and the trigger efficiency has been checked using events with similar topology like bhabhas and $e^+e^- \rightarrow \gamma\gamma(\gamma)$. The detector noise has been investigated with randomly triggered beam-gate events. The KORALZ prediction has been compared to the NUNUGPV [11] one. These two generators agree better than 1% while NUNUGPV claims a theoretical error of 8 % on the multi-photon cross section. This is however not enough to explain the deficit of data. We also compared the results with the 3 other LEP experiments preliminary results. Two, DELPHI [12] and OPAL [13], have a good agreement between data and Standard Model prediction (15 for 14 expected with 158 pb^{-1} luminosity for DELPHI and 24 for 26.7 expected for OPAL with 187 pb^{-1} luminosity). ALEPH [14] reports a 1σ deficit (21 for 27 expected with 173.6 pb^{-1} luminosity).

As the other experiments has a rather good agreement between data and standard model prediction, it is very unlikely that the 3σ deficit could be explained by a not yet predicted new phenomenon. The best explanation is thus a statistical underfluctuation. If it is not, the deficit will be maintained during the 99 LEP run.

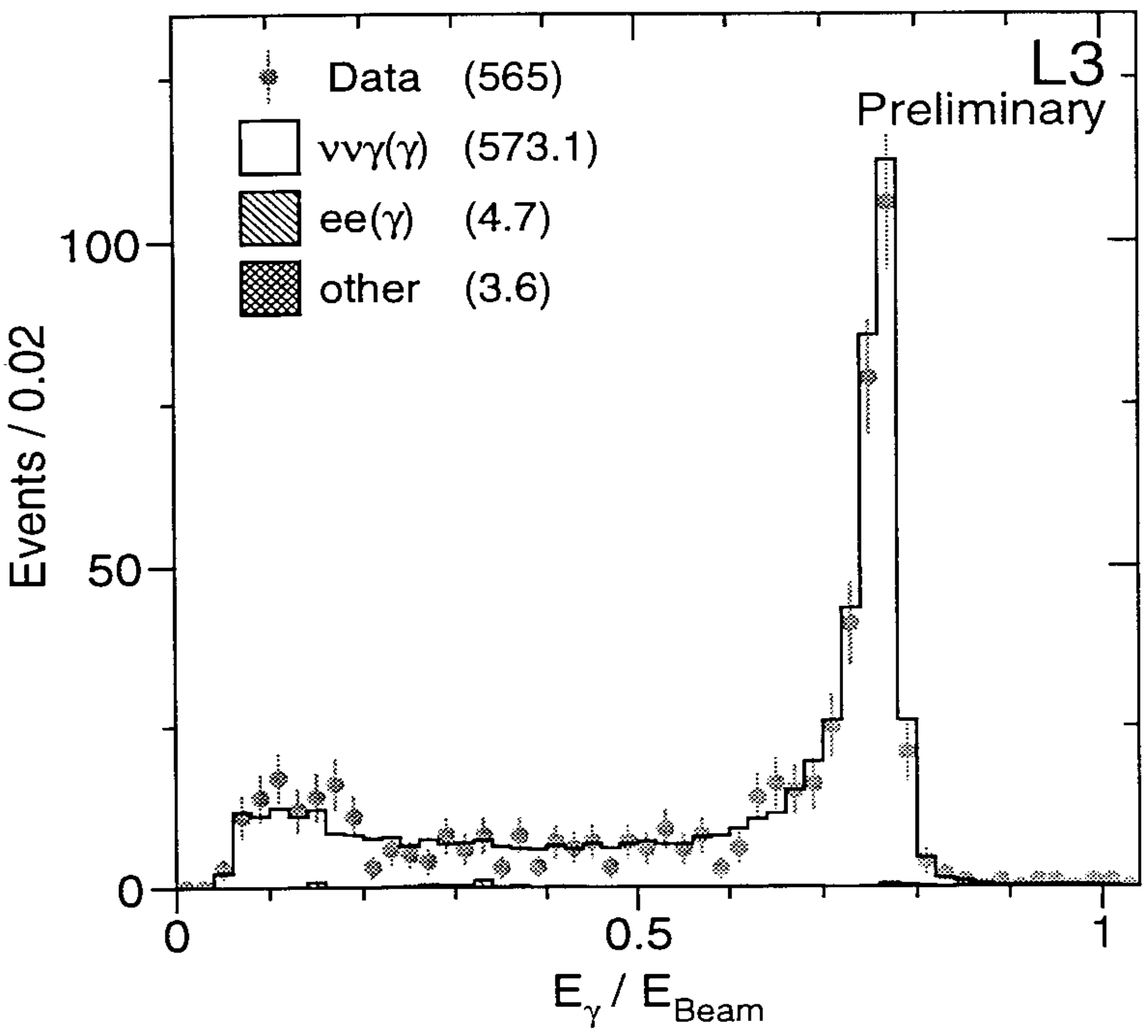

Figure 1: Energy distribution for the most energetic photon for single photon and 2 photons events.

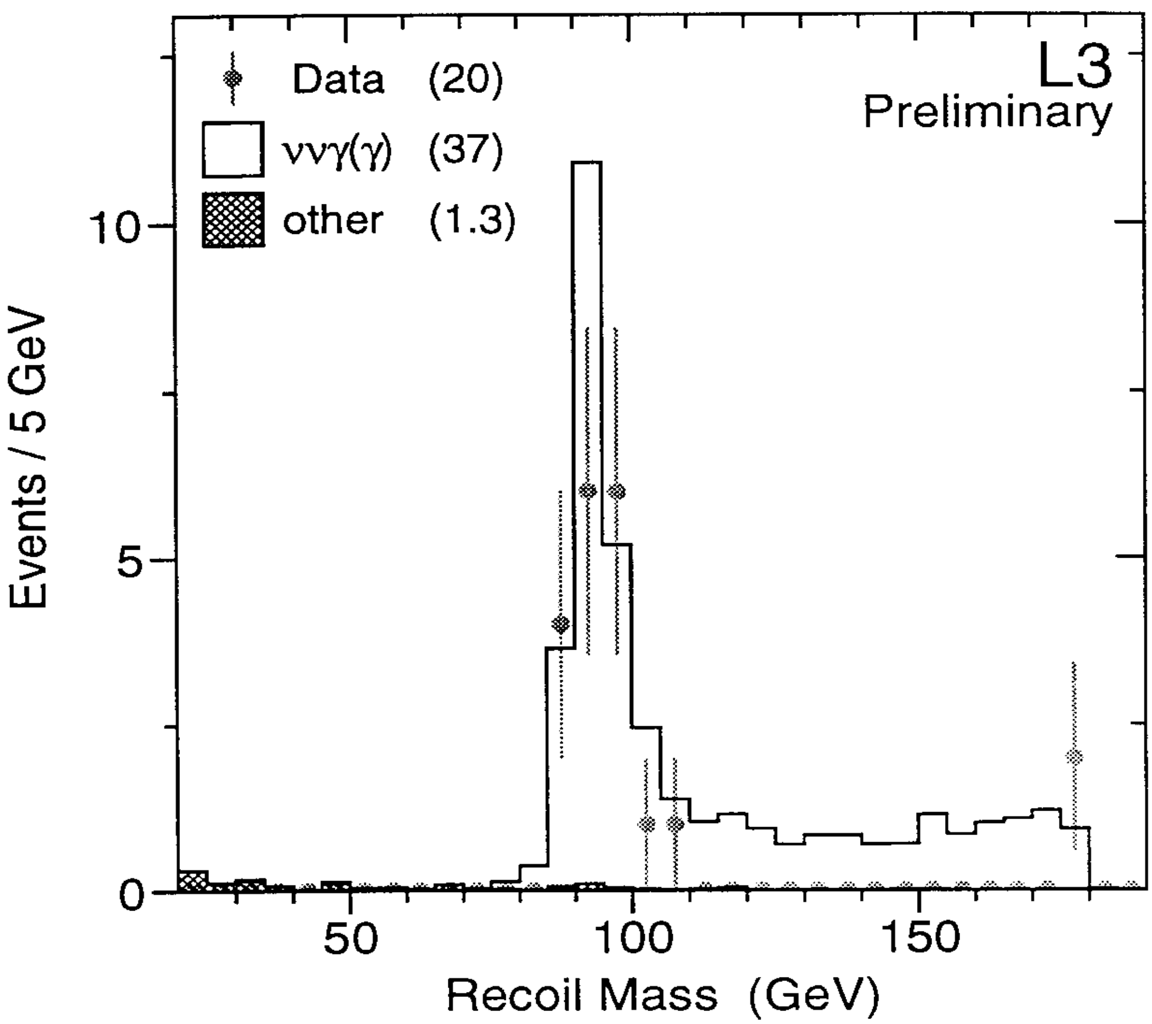

Figure 2: Recoil mass distribution for 2 photons events.

4 Interpretation for SUSY

As no excess of events, signature of SUSY signal, have been found, limits were derived for various SUSY models. Those results can be used to test some explanations of the $e^+e^-\gamma\gamma \not{E}_T$ CDF event. All the SUSY processes were simulated with the SUSYGEN [15] generator.

4.1 Supergravity-MSSM

This model is the minimal supersymmetric extension of the Standard Model. For large regions in the model parameter space, the LSP is the $\tilde{\chi}_1^0$. In this model the $\tilde{\chi}_2^0$ can decay to $\tilde{\chi}_1^0\gamma$ via loop diagrams like the one shown in figure 3 [16] [17]. This decay mode is important when the tree-level decay mode $\tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0 f\bar{f}$ is suppressed. This happens when the $\tilde{\chi}_1^0$ and $\tilde{\chi}_2^0$ are

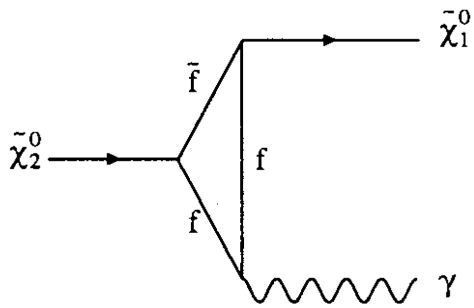

Figure 3: One of the Feynman diagram for the decay $\tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0\gamma$.

of opposite natures : one is gaugino and the other is higgsino [17]. This configuration is very rare if we assume the GUT relation $M_1 = \frac{5}{3}\tan^2\theta_W M_2$. But if we relax this relation, one can find region of the parameter space which leads to such opposite natures for the two lightest neutralinos. This is the case for the following set of parameter [17] :

$$\begin{cases} M_1 \simeq M_2 \\ \tan\beta \simeq 1 \\ \mu < 0 \\ \frac{M_Z}{2} < M_2 < M_Z\frac{1+\sqrt{3}}{2} \end{cases}$$

Assuming a 100% branching ratio for $\tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0\gamma$, we derived 95% confidence level upper limits on the cross section of the process $e^+e^- \rightarrow \tilde{\chi}_2^0\tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0\tilde{\chi}_1^0\gamma\gamma$. The result is shown in figure 4 as a function of $\tilde{\chi}_1^0$ and $\tilde{\chi}_2^0$ masses. To obtain those limits, we add to the 2 photons selection the requirement that the energy of each photon should be compatible with the kinematics of the signal for a given couple of neutralino masses. An excluded upper limit between 0.04 pb and 0.07 pb for the main part of the $M_{\tilde{\chi}_1^0}$-$M_{\tilde{\chi}_2^0}$ plane has been put.

These upper limits have been translated into a 95 % CL excluded region in the $\tilde{e} - \tilde{\chi}_2^0$ mass plane as shown in figure 5. It is assumed that the $\tilde{\chi}_1^0$ is pure higgsino and that $\tilde{\chi}_2^0$ is pure photino (scenario that may explain the CDF event.). The double hatched region corresponds to $M_{\tilde{e}_L} \gg M_{\tilde{e}_R}$ and the hatched region is additionaly excluded when $M_{\tilde{e}_L} = M_{\tilde{e}_R}$. This plot also shows the kinematically allowed regions to explain the CDF event via a selectron pair production $p\bar{p} \rightarrow \tilde{e}^+\tilde{e}^-X$ and then $\tilde{e}^+\tilde{e}^- \rightarrow e^+e^-\tilde{\chi}_2^0\tilde{\chi}_2^0 \rightarrow e^+e^-\gamma\gamma\tilde{\chi}_1^0\tilde{\chi}_1^0$ [18]. Those regions are labelled by the $\tilde{\chi}_1^0$ mass in GeV.

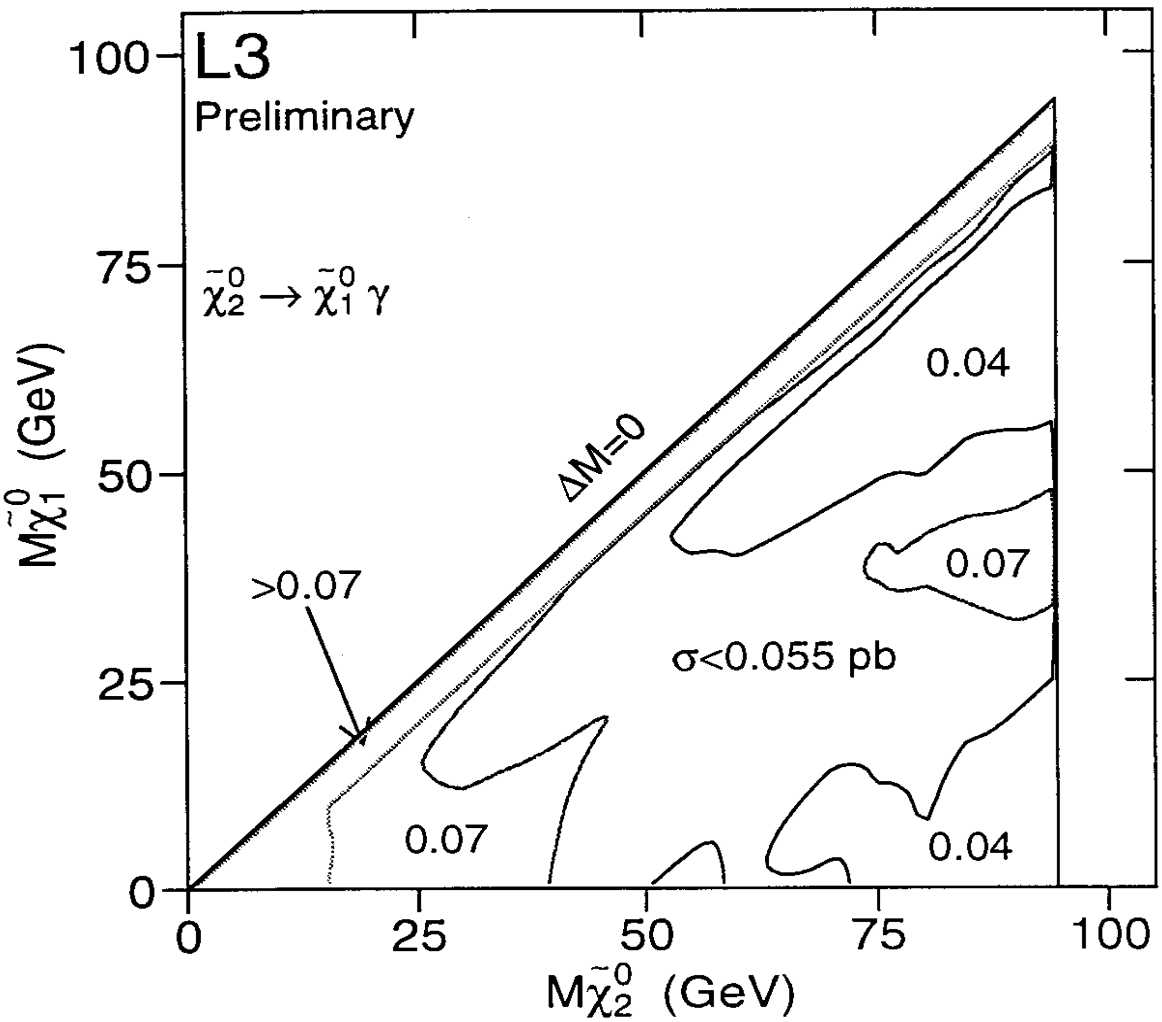

Figure 4: 95 % CL upper limit on the cross section of the process $e^+e^- \rightarrow \tilde{\chi}_2^0\tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0\tilde{\chi}_1^0\gamma\gamma$ in Supergravity models.

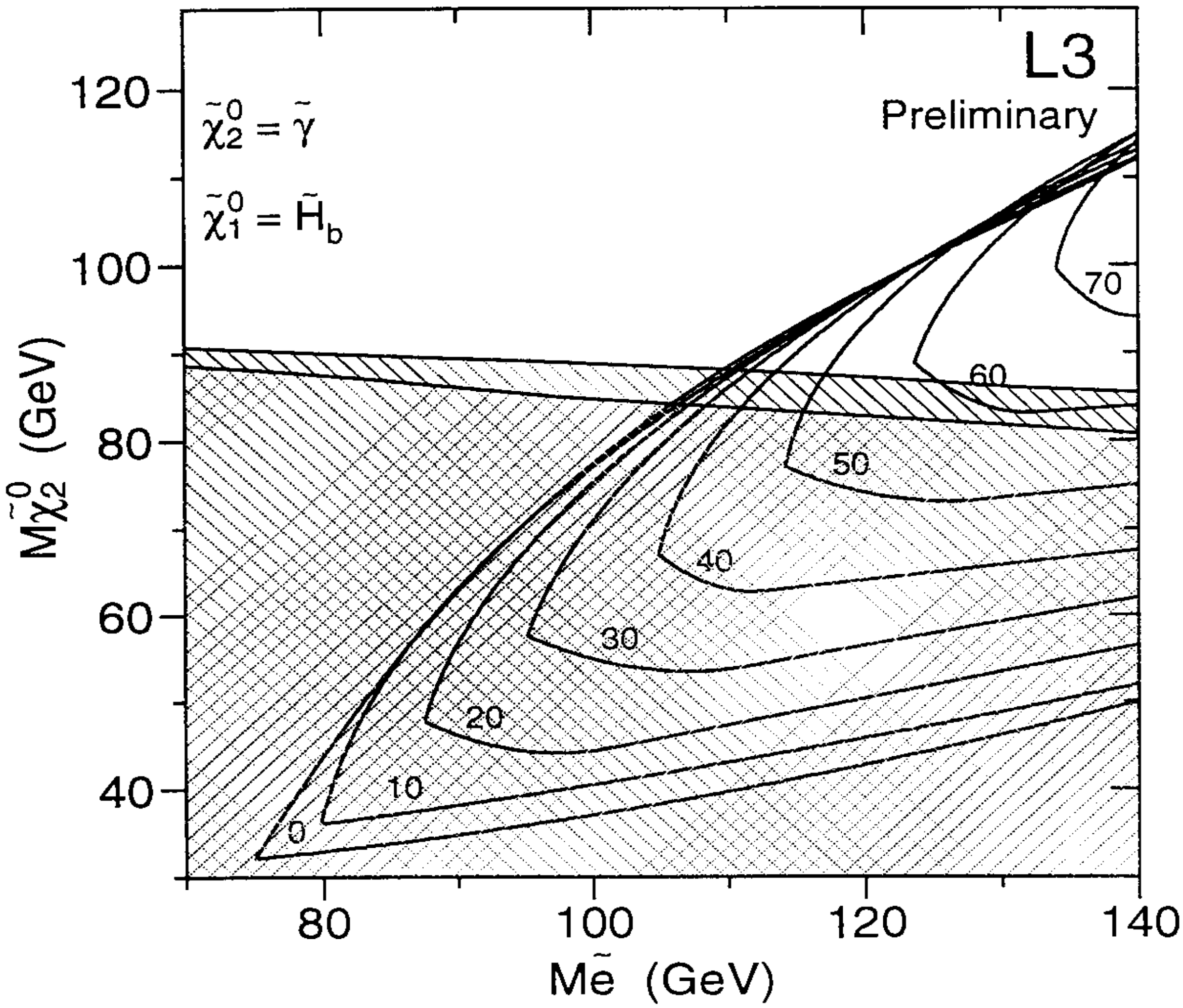

Figure 5: 95 % CL excluded region for Supergravity models. It is assumed that the $\tilde{\chi}_1^0$ is pure higgsino and that $\tilde{\chi}_2^0$ is pure photino . The double hatched region corresponds to $M_{\tilde{e}_L} \gg M_{\tilde{e}_R}$ and the hatched region is additionaly excluded when $M_{\tilde{e}_L} = M_{\tilde{e}_R}$. This plot also shows the kinematically allowed regions to explain the CDF event via a selectron pair production $p\bar{p} \rightarrow \tilde{e}^+\tilde{e}^-X$ and then $\tilde{e}^+\tilde{e}^- \rightarrow e^+e^-\tilde{\chi}_2^0\tilde{\chi}_2^0 \rightarrow e^+e^-\gamma\gamma\tilde{\chi}_1^0\tilde{\chi}_1^0$. Those regions are labelled by the $\tilde{\chi}_1^0$ mass in GeV.

4.2 GMSB

In this model, the Supersymetry Breaking is dynamic and occurs at lower energy scale in a hidden sector. It is then propagated to the visible sector via new gauge interactions which belongs to a so-called messenger sector [19]. In this model, the LSP is the gravitino $\tilde{G}$ which is light. Its mass is typically between 1 eV and 10 keV. The $\tilde{G}$ mass is related to the SUSY breaking scale F by the relation :

$$M_{\tilde{G}} = \frac{F^2}{\sqrt{3}M_p}$$

where M_p is the Planck mass. Gravitino mass above 10 keV are not realistic because the gravitino contribution to the dark matter would then close the universe [20] [21]. On the other hand, gravitino mass should be greater than 1 eV to avoid too fast cooling of red giants and supernovae [21].

The $\tilde{\chi}_1^0$ decays in $\tilde{G}\gamma$ via its photino component. The branching ratio is 100% if the $\tilde{\chi}_1^0$ is pure photino. Nevertheless, GMSB models prefer $\tilde{\chi}_1^0$ which are mainly bino.

Using the same techniques as for the MSSM we can for this model derive a 95% CL excluded region in the $\tilde{\chi}_1^0 - \tilde{e}$ mass plane which is the hatched region in figure 6. This region has been derived using the 2 photons process $e^+e^- \to \tilde{\chi}_1^0\tilde{\chi}_1^0 \to \tilde{G}\tilde{G}\gamma\gamma$ and assuming the $\tilde{\chi}_1^0$ is pure bino and also that $M_{\tilde{e}_L} = M_{\tilde{e}_R}$. Also shown is the kinematically allowed region for the CDF event through a $\tilde{e}$ pair production : $p\bar{p} \to \tilde{e}^+\tilde{e}^-X$ and $\tilde{e}^+\tilde{e}^- \to e^+e^-\tilde{\chi}_1^0\tilde{\chi}_1^0 \to e^+e^-\tilde{G}\tilde{G}\gamma\gamma$ [22]. We can see that this explanation of the CDF event is almost ruled out.

4.3 No scale Supergravity : LNZ

In this model, the local Susy breaking which gives the gravitino mass is not realized at the same energy scale than the global Susy breaking which is responsible for the MSSM soft breaking mass terms (m_0, $m_{\frac{1}{2}}$). This can lead to a very light gravitino ($M_{\tilde{G}}$ is typically of the order of the μeV) with all the other Susy particles heavy.

For the specific LNZ model [23] [22], the phenomenology is similar to the GMSB one. The LSP is the $\tilde{G}$ and the NLSP is a bino-like $\tilde{\chi}_1^0$. In this model, all the mass spectrum and all the cross sections are determined by the $\tilde{G}$ mass and one additional parameter.

Using the single photon process $e^+e^- \to \tilde{\chi}_1^0\tilde{G} \to \tilde{G}\tilde{G}\gamma$ whose cross section is scaled with $\frac{1}{M_{\tilde{G}}^2}$, we can derive a 95% CL excluded region in the $\tilde{\chi}_1^0 - \tilde{G}$ mass plane as shown in the figure 7. For example, for a 100 GeV $\tilde{\chi}_1^0$, gravitino masses under 25 μeV are excluded.

5 Conclusion

We have studied multi-photon events with missing energy with the data collected at $\sqrt{s}$= 189 GeV during the 1998 LEP run. Those data correspond to an integrated luminosity of 176 pb^{-1}. A good agreement between data and Standard Model prediction is observed for single photon events whereas a 3σ deficit of data appears in 2 photons with missing energy. This deficit could be due to a statistical underfluctuation.

Since no excess of events have been found, new preliminary 95% CL excluded regions were derived in $\tilde{\chi}_2^0 - \tilde{e}$ mass plane for MSSM model, $\tilde{\chi}_1^0 - \tilde{e}$ mass plane for GMSB models and in $\tilde{\chi}_1^0 - \tilde{G}$ mass plane for LNZ. In particular, the excluded region for GMSB models almost covered the kinematically allowed region for the explanation of the CDF event through $\tilde{e}$ pair production scenario

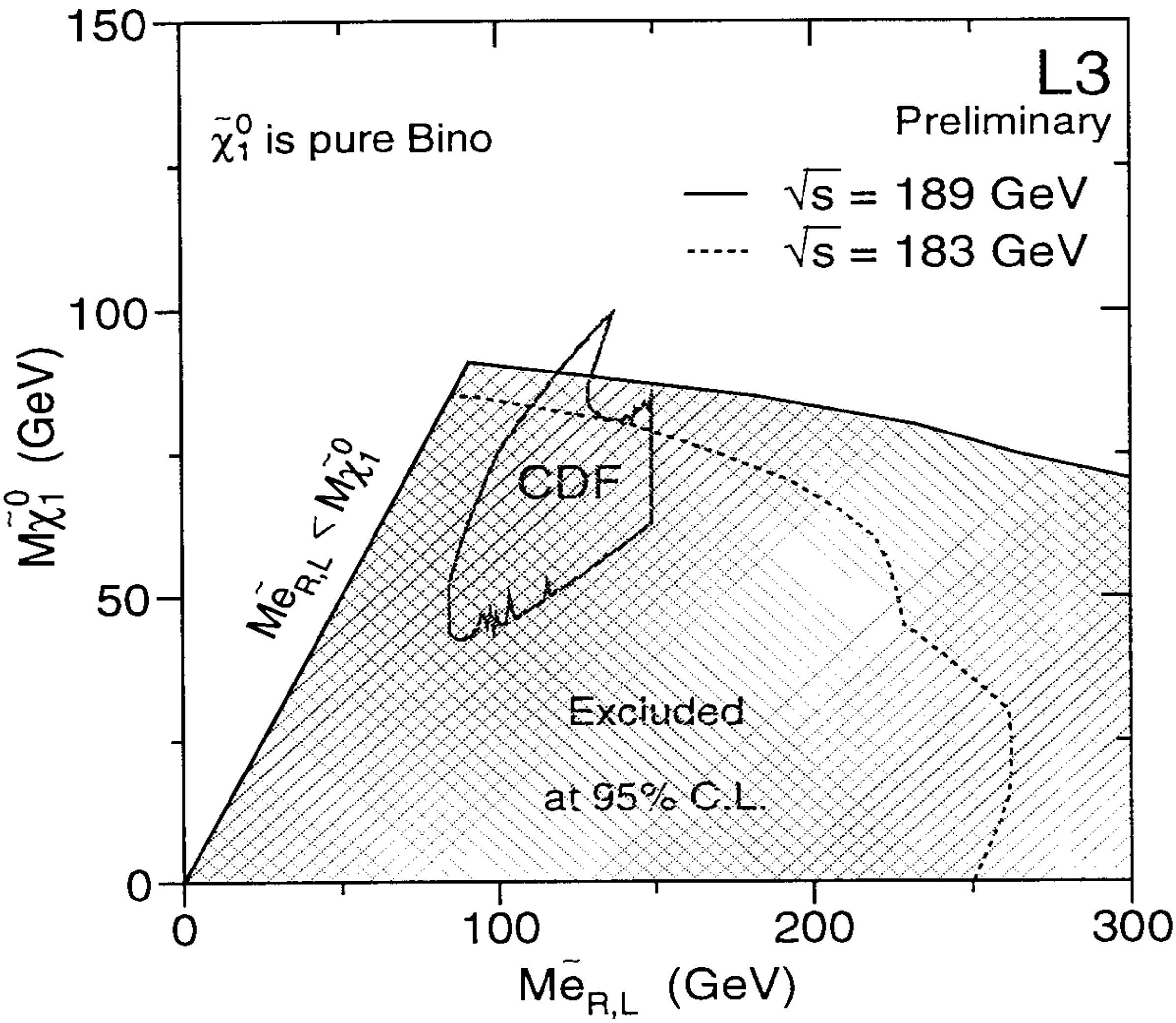

Figure 6: 95 % CL excluded region for GMSB models derived from 2 photons events. It is assumed that the $\tilde{\chi}_1^0$ is pure bino and that $M_{\tilde{e}_L} = M_{\tilde{e}_R}$. Also shown is the kinematically allowed region for the CDF event through a $\tilde{e}$ pair production : $p\bar{p} \to \tilde{e}^+\tilde{e}^-X$ and $\tilde{e}^+\tilde{e}^- \to e^+e^-\tilde{\chi}_1^0\tilde{\chi}_1^0 \to e^+e^-\tilde{G}\tilde{G}\gamma\gamma$.

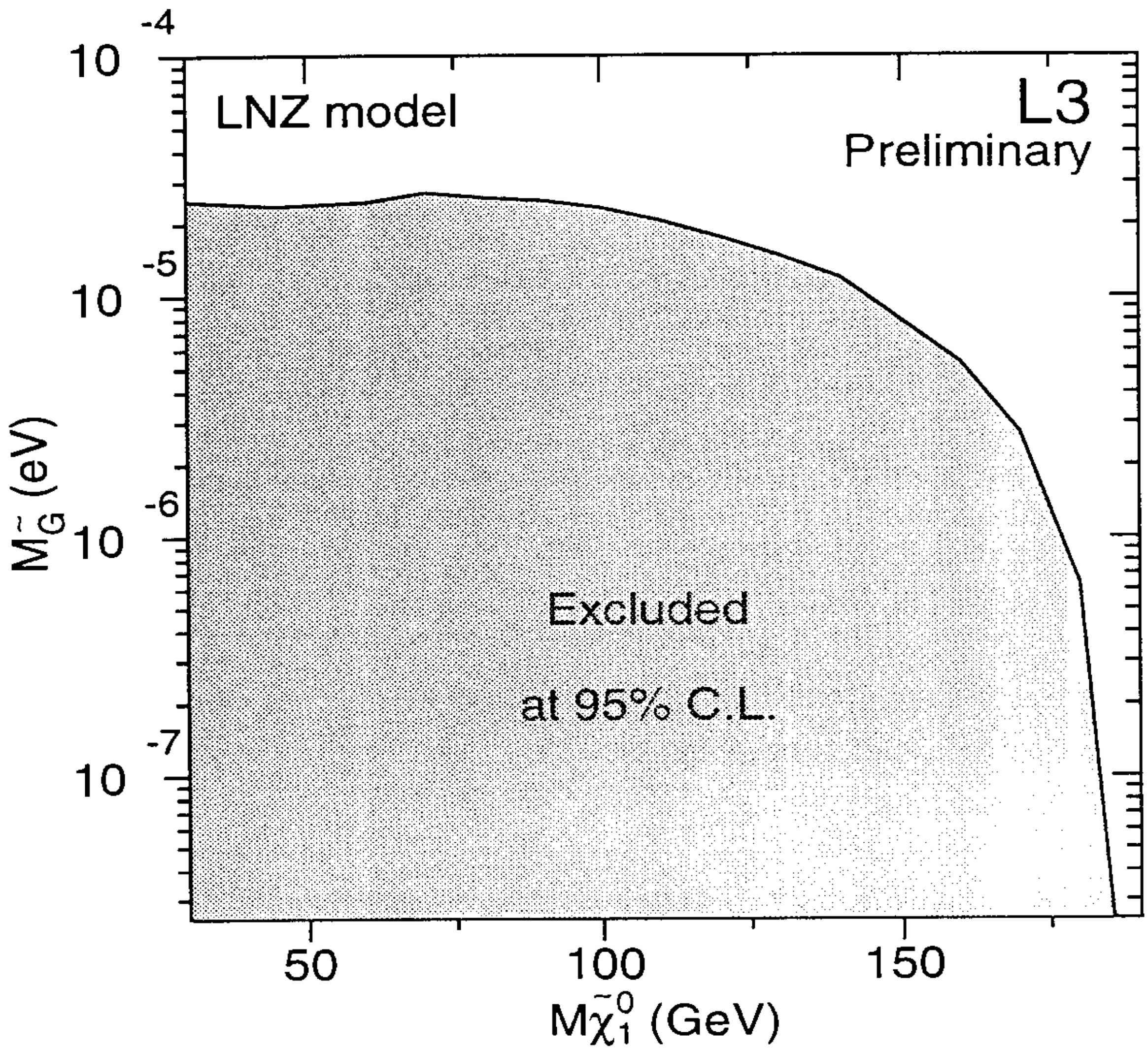

Figure 7: 95 % CL excluded region for LNZ model derived from single photon events.

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